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Evaluation Of The Nuclear Compaction Test Method- District 3

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John L. Beaton

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Materials and Research Department

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16. ABSTRACT

Introduction:

The Materials and Research Department of the Division of Highways is currently undertaking an extensive research program to evaluate the application of a modified statistical test method using nuclear soil gages to control soil compaction. The basic goal of this study is to determine the feasibility of using this test method in California highway construction. The extent that nuclear testing and the statistical approach will be utilized in construction control of earthwork will be determined by the outcome of this research project.

This report is the first of eleven, from the projects in ten of our eleven highway districts involved in this study. the project is located in Sacramento county between Route 99 and the Sacramento River near Elkhorn, approximately 4.8 miles in length. The location map, shown in Figure 1, illustrates the general layout of the project. Two lanes of an ultimate four-lane freeway were constructed with Portland cement concrete surface on cement treated base over lime treated subgrade.

It is the purpose of this report to examine the application of the test method to specification control on this project and analyze the data obtained from the field operation of the nuclear equipment. Conclusions and recommendations will not be made until a final report is prepared combining information obtained from all of the projects.

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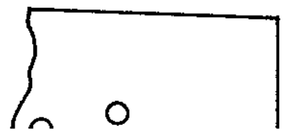
EVALUATION OF THE NUCLEAR COMPACTION TEST METHOD

DISTRICT 03



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MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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State of California
Department of Public Works
Division of Highways
Materials and Research Department

September 15, 1966

Lab Auth 632697-1
HPR-1(2), F-04-03

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

INTERIM REPORT #1

on

EVALUATION OF THE

NUCLEAR COMPACTION TEST METHOD

District 03

Study made by .... Foundation Section
Under general direction of ..... Travis Smith
Work supervised by .... W. G. Weber, Jr.
Report prepared by .... D. R. Howe
Bobby Lister

Very truly yours,

J Beaton

JOHN L. BEATON
Materials and Research Engineer

Attach
cc: LR Gillis
AC Estep
JF Jorgensen
WL Warren -(2)
CG Beer
Research Files
H Lopez

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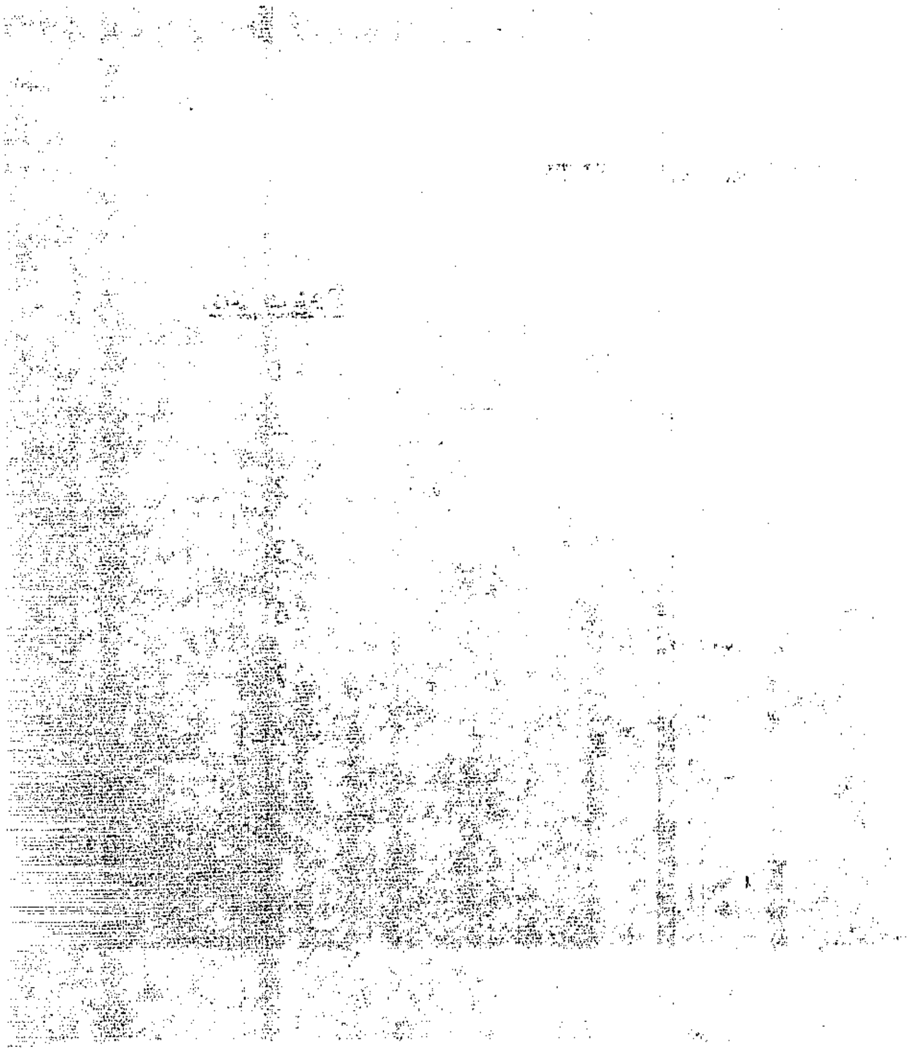

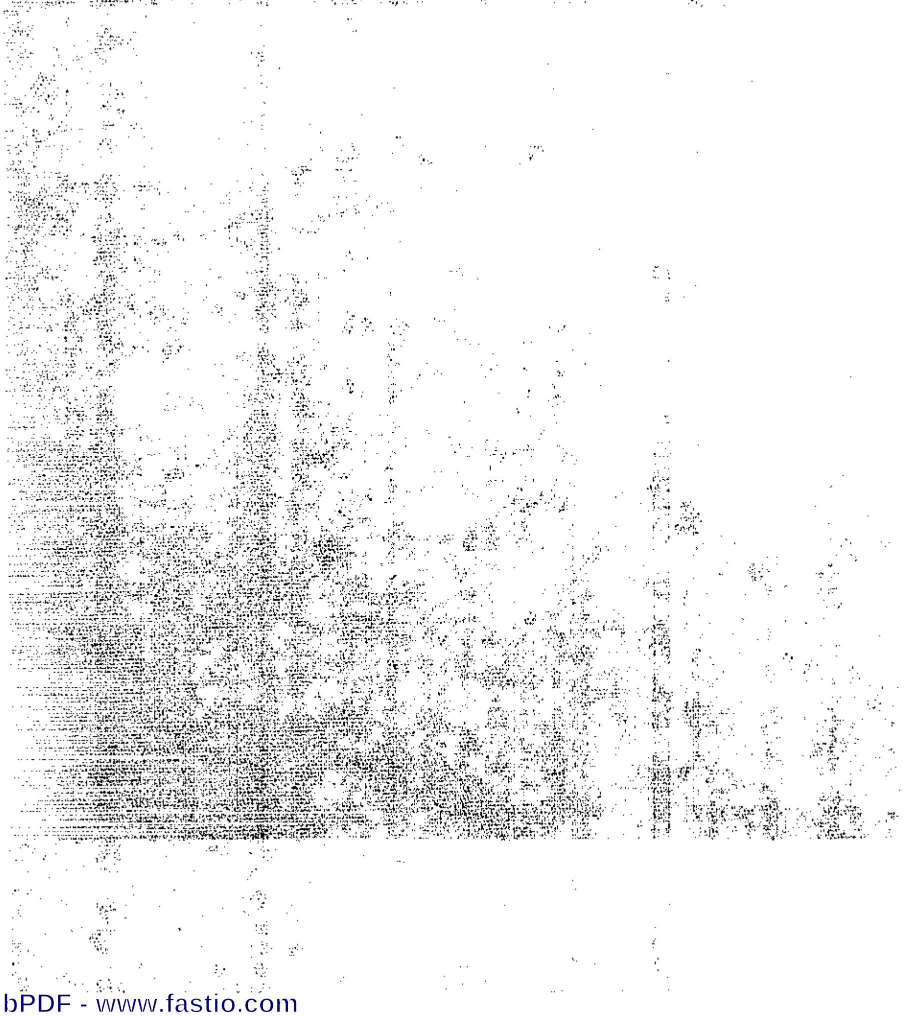

Acknowledgments

The construction contract where this study was conducted was under the general supervision of the District 03 Construction Engineer and under the direct supervision of the Resident Engineer. Considerable credit is given to the Assistant Resident Engineer and the two test operators for their efforts in the successful application of the nuclear gages. Supervision of the nuclear test method and operational liaison was undertaken by the Materials and Research Department.

This research study was financed with Bureau of Public Roads 1½ percent research funds under authorization HPR 1(2) F-04-03.

Introduction

The Materials and Research Department of the Division of Highways is currently undertaking an extensive research program to evaluate the application of a modified statistical test method using nuclear soil gages to control soil compaction. The basic goal of this study is to determine the feasibility of using this test method in California highway construction. The extent that nuclear testing and the statistical approach will be utilized in construction control of earthwork will be determined by the outcome of this research project.

This report is the first of eleven, from the projects in ten of our eleven highway districts involved in this study. The project is located in Sacramento County between Route 99 and the Sacramento River near Elkhorn, approximately 4.8 miles in length. The location map, shown in Figure 1, illustrates the general layout of the project. Two lanes of an ultimate four-lane freeway were constructed with portland cement concrete surface on cement treated base over lime treated subgrade.

It is the purpose of this report to examine the application of the test method to specification control on this project and analyze the data obtained from the field operation of the nuclear equipment. Conclusions and recommendations will not be made until a final report is prepared combining information obtained from all of the projects.

Method of Operation

In order to establish the new test method as the method of compaction control on this contract, it was necessary to place the following statement in section 5-1.03 of the contract special provisions:

> "Wherever relative compaction is specified in the standard specifications to be determined by Test Method Nos. Calif. 216 or 312 the relative compaction will be determined by experimental nuclear Test Method No. Calif. T-231. Copies of this experimental test method may be obtained at the Materials and Research Department, Division of Highways, Sacramento, California, and will be furnished on request."

The experimental nuclear Test Method No. Calif. T-231-B is shown in Appendix A.

The Assistant Resident Engineer, two technicians, and a progress sampler were given a one-week course of instruction in Sacramento. The course included the basic concepts of nuclear physics, health safety, application of the test method, and operation of nuclear equipment.

A Hidrodensimeter Model HDM-2 combination moisture and density gage was used on this project (See Fig. 2). This gage has a 5.4 millicurie Radium-Berylium source and can be used as a Compton backscatter type gage. By attaching a rod, which contains a geiger mueller tube, this gage can also be used as a transmission type gage. This project utilized the Compton backscatter effect exclusively. The moisture portion of the gage measures the effect of neutron moderation by soil water.

In the initial phases of the project, the nuclear testing involved the undertaking of both density and moisture calibrations on the soils encountered, in accordance with Test Method No. Calif. 231-B (see Appendix A). Several density calibration curves were established for the different types of materials on this project (see Figures 3, 4, 5, and 6). The moisture calibration curve did not change due to different soil types (see Figures 7 and 8), therefore, one curve was used throughout the contract.

The area concept was used in measuring the earthwork compaction (see Appendix A). The general practice on this project was to select at random six test sites with the same material type covering an area not exceeding a thousand foot length of roadbed without use of sections. A minimum of three test sites were used for the backfill around pipes. An in-place nuclear density and moisture test was performed at each site within the area.

In the early stages of construction a sample of soil was obtained for the Impact Compaction test from the site of the nuclear test nearest to the average nuclear density value within the area being tested. The maximum density thus obtained would then be used to compute the relative compactions from the individual nuclear tests within this area. After considerable impact data had been accumulated, the average maximum density for the particular soil type under nuclear test was used to calculate relative compaction values.

Illustrated in Figure 9 is the frequency distribution of the dry density impact tests of all the different materials. An indication of the differences in the physical characteristics of the materials may be seen from these results.

Analysis of Data

Calibration

The Hidrodensimeter moisture and density gage serial number 187 was intended to be used throughout this project but due to several malfunctions at various times (see Table I) an identical gage, Hidrodensimeter serial number 163, had to be substituted. Although these gages have the same manufacturer and are the same model, a separate calibration "curve" had to be established for each gage (see Figures 3, 5, 7 and 8). These curves were plotted from the data in Table II.

The majority of the embankment soil and all of the lime treated subgrade came from two borrow sites, "Porter Pit" and "Lone Tree Pit." The soil from these two borrow sites was very similar; silty clay with some black gumbo.

Separate calibration curves were used for both the embankment and lime treated subgrade from each of the two borrow sites. The aggregate subbase, aggregate base, and cement treated base also had separate calibration curves. From Figures 3 and 5 it appears that two or three calibration curves could have been used for each gage for all the soils encountered. The density calibration curves were constructed assuming a linear correlation between nuclear count and soil density from the data in Table II.

The soil densities used to correlate with the nuclear count were obtained by two different methods:

(1) An aluminum mold (Figure 10) approximately 2 cu. ft. in volume was used for densities of aggregate subbase and aggregate base because of the difficulty in determining a density by the sand volume method in this type of material.

(2) Sand volume densities were used for all the other materials on this project.

The straight lines were drawn through the plotted data at locations of estimated "best fit," (i.e., estimated without calculation) and were used for construction control. The precision of the calibration data, calculated in terms of the standard deviation from the estimated best fit line, is illustrated in Table III for each of the soil types.

The moisture calibration data shown in Figures 7 and 8 were plotted as "oven dry" moisture content (in lbs. of water per cubic foot) versus nuclear count. Assuming linear correlation between these two variables, a straight line was drawn through the plotted data at estimated "best fit," and was used for field moisture determination. These calibration curves were plotted from the data in Table IV. The standard deviation of the data from Hidrodensimeter 187 was 2 lbs. per cu. ft. and from Hidrodensimeter 163 was 5 lbs. per cu. ft. One moisture calibration curve sufficed for all soils.

The "dry weight basis" was used to calculate the relative compaction for the entire project. A nuclear moisture content (lbs. of water per cubic foot of soil) was obtained at each test site to establish the dry in-place density.

Construction Control Testing

The relative compaction (RC) data are shown in Table V and VI for embankment and structure backfill (including AB, AS, CTB and LTS), respectively. The tables are arranged to display the test values at the individual sites as well as the averages for the various areas tested. Those areas which do not meet the relative compaction specification requirements for the particular material tested are underlined to indicate that they are "failing" or unacceptable areas.

Frequency distribution (histogram) charts of relative compaction values are shown in Figures 11 and 12. They were constructed from the data in Tables IV and V, respectively for individual test sites. Tests from passing areas are shown as solid bars while the values from failing areas are indicated by dashed lines. Figures 13 and 14 are similar plots of area averages.

It is noted from Figure 11 that the individual tests from the passing embankment areas (solid bars only) range from a low of 76% RC to a high of 108% RC. The average for this distribution is 92 and the standard deviation is 5.

While the majority of the individual tests from the passing areas were at or above the minimum 90% RC specification for the embankment, it can also be seen in Figure 11 that there is a small group of substandard RC values scattered through these areas. These tests represent about 10 percent of the total tests from the passing areas.

Eighty-five percent of all the relative compaction tests were taken on structure backfill, AB, AS, CTB, and LTS. The trend shows a pattern similar to the embankment as illustrated in Figure 12. The passing areas indicate a range of 84 percent to 112 percent RC, an average of 97 percent, and a standard deviation of 4. There are about 14 percent of the individual tests from the passing areas which fall below the minimum specification of 95 percent RC.

It should be noted, in the above statistical analysis, that the tests from the failing areas (shown as dashed bars in Figures 11 and 12) were not included in the calculations. The primary reason is that the failing areas were reworked by the contractor and retested until the area averages met the specification limit. As a consequence these failing values no longer relate to the finished product and the acceptable retest values are included with the original tests for the passing areas. The purpose of showing the failing area tests, in the figures, was merely to provide an impression of the proportion and distribution of these tests encountered during construction operations.

The distribution charts for the area averages of both types of material are shown in Figures 13 and 14. It is to be expected, in these charts, that the passing area will only extend from the relative compaction specification limit upward, since the failed areas are normally reworked and retested until they too become passing areas. However, it should be pointed out that this does not present an entirely true representation of the probable final state of compaction. Besides the statistical effect of increasing the probabilities of obtaining passing samples through retesting, as demonstrated by Jorgensen and Watkins (1), the limitations of sampling tends to result in a distorted impression of the true "universe" conditions. The normal or bell shaped curves, superimposed on the respective charts, indicate the most probably distribution for all possible test areas (universe distribution) for each material. It can be seen that a portion of each distribution curve extends somewhat below 90% and 95% RC, indicating that some material may still be below the specification limit. The relative compaction data is plotted in Figures 15 and 16 for only those areas whose averages do not meet the minimum specification requirements. Individual test points and area averages are plotted against relative compaction in the ordinate. In the abscissa the areas are grouped in proportion of passing to failing tests with the "passing" ratio diminishing from left to right (e.g. 67%: 33%; 50%: 50%; 33%: 67%; etc.) Within the groups the areas are generally arranged to show increasingly unsatisfactory test values to the right.

For embankment (Fig. 15) it can be seen that only one group has 33% failing tests with an average of 89 % R.C. Although the averages are above 90% RC for the next three groups of tests, they are failing areas because 50% of the individual tests were below 90% RC. When the proportion of failing tests increases to 67%, 83%, and all failing, the test averages drop off quite rapidly. A similar situation exists in the case of structure backfill, AB, AS, CTB, and LTS (Fig. 16) where it is noted that there are no failing areas tested on the project having less than 50% of the tests failing and that the area averages decrease as the number of individual tests increase. Table VII combines the results of Figures 15 and 16. This data indicates that in 87% of all the test areas whose averages failed, 2/3 of the individual tests were also below the minimum RC requirement. Table VII also shows that 10.8% of all the test areas failed by the 2/3 requirement but had averages above the minimum specification. This indicates that both of these requirements must be satisfied for compaction control. The fact that areas failing by virtue of sub-specification averages normally contain a perponderance of failing tests provides further evidence to support the contention that areas containing more than 33% or 1/3 failing tests should automatically be classed as failed areas, even though the area average occasionally meets the specification requirement.

Discussion of Test Operations

During this project a few difficulties arose, but these were overcome immediately. These problems will be discussed in the following paragraphs.

At the beginning of this project, the operators were spending too much time preparing the test site for the nuclear gage. As experience was gained, one operator would get a "cat" or a "blade" to level 6 sites and prepare them for the nuclear gage, while the other operator would take nuclear counts. Whether the area "passed" or "failed" the required relative compaction could be calculated by using an established maximum density on the material as soon as the in-place density was taken. The contractor was satisfied with these immediate results because he could either place and compact the next lift or rework the same area.

Although the nuclear gage assigned to the project was out of service 28 percent of the total working days (see Table I), it did not present a problem to the project. There was an "emergency" gage supplied by the Materials and Research Department that was used during these periods of repair.

The health-safety aspects of nuclear testing did not present any difficulties on this project. There was no apprehension indicated at any time by either the State employees, the contractor, or the general public. Each operator and the assistant resident engineer were equipped with film badges and dosimeters to monitor exposure. The average weekly dosage received by these people did not exceed 4 milliroentgens equivalent man (mrem). The highest dosage received by the test operators in any one week was 7 and 4 mrem, respectively. This is well below a 50 mrem per week limit normally observed by this department or the 100 mrem maximum allowable specified by the California State Department of Public Health.

The transportation of the nuclear gage imposed no problem. The gage was transported to the test areas in the rear of a four-wheel drive vehicle with a pickup body. A special locked container with seat belts was constructed and fastened to the vehicle to protect the nuclear gage from theft, wet weather, and excessive jarring.

References

"Compaction-Myth or Fact?" by J. Frank Jorgensen and Robert O. Watkins, presented at the 44th Annual WASHO Conference, June 16, 1965.

TABLE I

Record of Nuclear Gage Malfunctions

Hidrodensimeter 187

Description of Malfunction	Date Gage out	Date Back on job	Downtime Working Days
Hasp broken on probe, source can not be locked in safe position (used padlock around the handle) repaired 11-12-65.	9-8-65	Continued use with another lock	None
Moisture portion of gage would not count. Replaced high voltage input board.	9-20-65	9-21-65	1
Low-speed decade tube bad. Replaced.	9-24-65	9-24-65	None
Standard count dropped 11000 counts-spider connected to source replaced.	10-15-65	11-12-65	20
Density standard count dropped 4000 counts. High decade board replaced interconnecting cable also broken	1-26-66	2-1-66	4
Moisture portion of gage will not count (preamp replaced)	3-10-66	3-29-66	14
			39 Total

TABLE II

Counts per Minute versus Sand Volume in lbs per ft^3

HIDRODENSIMETER 187 - Density

Porter Pit Emb

Counts per minute	In-Place Density (lbs/ft^3) Sand Volume
37,880	108.3
38,600	105.9
37,510	115.6
40,750	115.3
39,240	97.4
36,060	112.4
37,688	103.8
35,162	121.6
34,977	127.2
36,570	112.1
34,480	124.7
34,540	128.6
34,960	118.8

Porter Pit LTS

c/m	Density
34,280	121.3
34,500	128.5
34,630	120.0
34,900	125.6
34,900	120.0
34,720	118.4
35,100	119.0
35,320	128.5
37,100	114.5

Verona Sand - Str. Backfill

c/m	Density
36,720	119.0
37,550	118.8
37,900	118.4
38,670	111.5
38,870	111.5
39,100	117.5
40,700	106.0

TABLE II - (contd)

Hidro 187
Density

Granite CTB

Counts per minute	In-Place Density(lbs/ft^3) Sand Volume
34,300	130.0
33,400	144.5
34,700	144.5
32,070	151.5
32,090	152.3
31,280	147.3
31,120	148.5

Agg. Subbase

c/m	Density
33,500	128.5
32,595	144.5
31,300	137.0
31,500	139.0
29,200	142.5
29,600	146.0
30,200	147.5
31,100	150.5
29,100	154.4

Granite - Agg. Base

c/m	Density
31,560	133.6
30,920	140.8
31,300	143.6
29,400	155.3

TABLE II - (contd)

HIDRODENSIMETER 163 - Density

Porter Pit Clay

c/m	Density
32,700	134.2
30,870	136.5

Porter Pit - LTS

c/m	Density
33,620	114.8
34,580	125.1
31,980	126.3
31,550	127.4

Lone Tree Clay

c/m	Density
31,700	122.5
31,200	137.6
29,950	128.5

Granite Agg. Subbase

c/m	Density
31,300	134.0
32,060	138.6
29,200	140.5
36,720	140.7
30,200	145.0
30,900	148.0
29,080	152.3

TABLE III

Standard Deviation of Density Calibration Tests
Hidrodensimeter 187

Soil Type	No. of Tests	Standard Deviation (p.c.f.) Best Fit Line
Embankment (from "Porter Pit")	15	7
Lime Treated Subgrade	10	7
Structure Backfill (Verona Sand)	7	4
CTB	7	6
Aggregate Base and Subbase	9	6

Hidrodensimeter 163

Soil Type	No. of Tests	Standard Deviation (p.c.f.) Best Fit Line
Embankment (from "Porter Pit")	2	*
Embankment (from "Lone Tree Pit")	3	*
Lime Treated Subgrade	5	2
Aggregate subbase	7	5

*Insufficient number of tests to properly determine a rational value for standard deviation

TABLE IV

Counts per Minute versus Oven Dry Moisture in lbs per ft^3

Moisture HDM 163

Counts per minute	Moisture $\#/ft^3$
2075	12.5
2100	14.75
2260	14.25
2640	20.25
2800	13.4
3370	23.75

Moisture HDM 187

Counts per minute	Moisture $\#/ft^3$
610	2.25
630	3.4
640	3.75
725	4.00
800	4.80
810	4.80
850	5.5
900	5.9
850	6.75
900	6.80
1050	5.9
1050	7.0
1220	7.2
1275	7.4
1320	7.7
1280	9.2
1550	8.5
1600	8.1
1675	8.0
1640	9.9
1575	9.3
1640	11.4
1725	10.25
1740	11.2
1700	14.7
1880	12.0
1930	10.0
1980	9.9
2075	12.5
2150	14.5
2190	11.7
2280	11.9
2300	14.5
2340	15.1
2370	14.0
2370	14.8
2650	16.4
2760	24.5
3000	20.0
3150	16.7
3160	19.9
3150	21.1
3430	22.4
3370	25.0
3760	29.8

90%

TABLE V

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
8-25-65	8	92	98	100	98	98	86	95	X		
"	9	94	95	91	85			91	X		
8-26-65	11	97	96	90	85			93	X		
8-27-65	12	85	86	91	95	97	90	91	X		
8-30-65	14	82	93	92				89		X	
"	15	90	97	95				94	X		
8-31-65	17	84	80	83				82		X	
9-1-65	18	93	98	89				93	X		Retest of Test #17
"	19	87	88	93	93	87	93	90		X	
9-3-65	23	89	91	88	97	90	85	90		X	
	25	85	82	95	89	87	96	89		X	
9-1-65	27	94	94	91	97	97	100	96	X		
9-8-65	29	88	86	88	96	95	90	91		X	
9-10-65	31	96	96	92	95	98	98	96	X		
9-11-65	32	95	91	79	92	89	92	90	X		
"	33	90	87	95	95	98	95	93	X		
9-13-65	34	95	91	90	98	97	95	94	X		
9-14-65	35	94	95	94				94	X		
9-15-65	36	84	84	84	80			83		X	
9-16-65	37	94	76	92	96	91	90	90	X		
"	38	81	85	86	83	85	87	85		X	
9-17-65	39	93	86	86	95	83	86	88		X	
9-18-65	40	86	93	86	87	88	88	88		X	
9-21-65	41	97	88	91	93	97	88	92	X		
9-22-65	47	93	95	96	91	85	96	93	X		

90%

TABLE V (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 | Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
9-24-65	53	94	87	93	94	91	90	92	X		
10-12-65	100	98	98	96				97	X		
10-18-65	113	105	105	86				99	X		
"	114	101	103	103	101	106	108	104	X		
10-28-65	140	95	101	102				99	X		
11-10-65	167	97	94	97	100	92	98	96	X		
4-26-65	235	97	88	97				94	X		
10-21-66	120	102	101	105	107	95	104	102	X		

95%

TABLE VI

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 | Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
8-26-65	10	85	89	87	98	98		92		X	
8-28-65	13	90	85	93	94	92	94	91		X	
9-21-65	42	99	96	94	100	89	93	95		X	
9-21-65	43	94	95	95	92	97	91	94		X	
"	44	97	95	97	99	93	93	95	X		
9-22-65	46	95	95	95	97	94	93	95	X		
9-23-65	48	96	86	87	91	88	95	91		X	
9-23-65	49	92	94	95				94		X	
"	50	94	92	96				94		X	
"	51	95	93	94	92	90		93		X	
9-24-65	52	93	83	92				89		X	
"	54	98	96	92				95	X		
"	55	101	98	101				100	X		
9-25-65	56	90	91	91	91	95	94	97		X	
"	57	96	96	98	99	90	100	97	X		Retest of #56
9-27-65	58	90	96	93	93	95	97	94		X	
9-27-65	59	93	96	99				96	X		
"	60	94	92	84				90		X	
"	61	97	96	98				97	X		
9-28-65	62	100	96	97				98	X		
"	63	98	96	92				95	X		
"	64	97	93	95				95	X		
"	65	97	93	97	97	101	97	97	X		

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 Cont. 03-061754

Date	Test No.	Relative Compaction, %							Accept	Reject	Remarks
		#1	#2	#3	#4	#5	#6	Avg.			
9-28-65	66	97	92	95	99	93	100	96	X		silty clay
9-29-65	67	100	97	97	101	96	90	97	X		silty clay
"	68	93	103	93	98	96	100	97	X		silty clay
"	69	102	104	101				102	X		sand
"	70	101	100	99				100	X		sand
"	71	101	100	96				99	X		sand
9-30-65	72	95	96	99				97	X		sand
"	73	103	102	99				101	X		sand
"	74	98	97	93				96	X		sand
10-1-65	75	99	90	91	91	93	97	94		X	Retest of #82 silty clay
"	76	104	102	105				104	X		sand
"	77	107	97	95	98	101		99	X		sand
10-4-65	78	98	95	97				97	X		sand
"	79	96	93	94				94		X	Retest of #80 sand
"	80	98	97	98				98	X		sand
"	81	98	104	102				101	X		sand
"	82	100	97	95	96	90	97	96	X		silty clay
10-5-65	83	87	93	90				90		X	Retest of #86 sand
"	84	100	97	94	100	94	97	97	X		silty clay
"	85	93	95	97				95	X		silty clay
10-6-65	86	93	95	97				95	X	Retest	of #83 sand
10-6-65	87	94	95	95				95	X		sand
10-6-65	88	101	100	99				100	X		sand
10-6-65	89	100	96	100				99	X		sand
10-6-65	90	100	101	96	101	103	100	100	X		silty clay

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 | Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
10-6-65	91	103	102	95	96	99	103	100	X		silty clay
10-7-65	92	100	98	99				99	X		sand
"	93	97	95	89	91	98	94	94		X	Retest of #96 silty clay
10-8-65	94	98	95	100				98	X		sand
"	95	86	94	86	86	93	94	90		X	Retest of #97 silty clay
"	96	102	99	92	93	97	98	97	X		silty clay
10-12-65	97	97	95	89	94	93	97	94		X	Retest of #104 silty clay
"	98	96	94	96				95	X		silty clay
"	99	Could not be completed									
10-13-65	102	96	99	96	98	94	101	97	X		clay and lime
"	103	96	94	112	110	109	100	103	X		" " "
10-14-65	104	103	97	84	100	103	105	99	X		silty clay
"	105	100	100	95	92	101	90	96	X		clay and lime
10-15-65	106	97	101	99	98	94	100	98	X		silty clay
"	107	98	101	101	103	106	107	103	X		black clay
10-16-65	108	105	102	104	105	101	98	103	X		clay and lime
"	110	101	98	105	104	100	105	102	X		clay and lime
"	111	103	104	100	92	105	109	107	X		clay and lime
10-18-65	112	110	99	106	100	111	108	106	X		clay and lime
"	115	101	104	100				102	X		sand
"	116	99	97	99				98	X		sand
10-19-65	117	101	101	97	94	97	100	98	X		silty clay
"	118	101	100	103				101	X		sand
10-21-65	119	104	92	97	109	96	107	101	X		silty clay
"	121	102	99	102				101	X		sand

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 | Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
10-22-65	123	101	103	103				102	X		sand
10-25-65	124	97	102	98				99	X		sand
"	125	104	103	102				103	X		sand
"	126	97	93	95				95	X		sand
"	127	104	99	95				99	X		sand
10-27-65	129	97	97	102				99	X		silty clay
"	130	92	97	106				98	X		silty clay
"	131	101	98	99	97	102	98	99	X		silty clay
"	132	101	102	97	100	99	99	100	X		silty clay
"	133	99	96	96				97	X		sand
"	134	95	99	96	99	99	95	98	X		sand
10-28-65	135	97	96	98				97	X		sand
"	136	95	95	95				95	X		sand
"	137	98	96	99				98	X		sand
"	138	95	93	98				95	X		sand
"	139	100	94	95				96	X		sand
10-29-65	141	105	100	99				101	X		sand
"	142	98	101	98				99	X		sand
11-1-65	143	95	97	95				96	X		silty clay
11-3-65	145	97	98	98	95	99	97	98	X		silty clay
"	146	100	97	100	96	97	95	98	X		silty clay
"	147	100	97	95				97	X		sand
"	148	94	99	99				97	X		sand
"	149	91	96	93	95	95	92	94		X	AS
11-4-65	151	98	95	97	95	96	102	97	X		AS

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 — Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
11-5-65	153	97	99	96	97	101	91	97	X		silty clay
"	154	101	98	98				99	X		silty clay
11-6-65	155	99	96	95	94	97	103	97	X		AS
11-6-65	156	98	98	97				98	X		AS
11-8-65	157	88	95	78				87		X	
11-9-65	158	104	99	100	91	102	99	99	X		L. T. subgrade
11-9-65	159	97	101	99				99	X		AS
"	160	99	102	95	100	102	101	100	X		L. T. S.
"	161	95	95	102	100	100	93	98	X		L. T. S.
"	162	100	97	105	106	104	99	102	X		L. T. S.
11-10-65	163	98	99	93	100	98	95	97	X		silty clay
"	164	94	100	97				97	X		silty clay
"	165	96	97	97	96			97	X		silty clay
"	166	93	95	93				95	X		silty clay
11-11-65	168	101	102	102	94	106	102	101	X		L. T. S.
"	169	104	101	105	102	104	111	105	X		L. T. S.
11-30-65	170	98	101	94	98	98	86	96	X		L. T. S.
12-1-65	171	95	96	98	101	95	98	97	X		L. T. S.
1-24-66	172										
"	173	98.9	93.9	96.9	93.3	96.0	98.6	96	X		L. T. S.
1-25-66	174	91.3	92.4	96.6	91.9	94.5	98.5	94		X	
"	175										
1-26-65	176	96	97	98	95	95	96	96	X		L. T. S.
1-28-66	177										
"	178	100	103	96	95	95	90	97	X		L. T. S.

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 Cont. 03-061754

Date	Test No.	Relative Compaction, %							Accept	Reject	Remarks
		#1	#2	#3	#4	#5	#6	Avg.			
1-28-66	179	84	96	98	95	96	93	94	X		L. T. S.
"	180	90	92	96	94	98	92	94		X	L. T. S.
1-29-66	181	94	99	104	97	100	94	98	X		L. T. S.
1-29-66	182	95	93	98				95	X		L. T. S.
2-16-66	184	94	96	84	97	98	92	94		X	CTB
2-17-66	185	97	90	92	89	95	96	93		X	L. T. S.
"	186	99	98	97	103	99	94	98	X		CTB
"	187	95	95	91	99	99	101	97	X		CTB
"	188	99	94	103				99	X		CTB
"	189	96	90	91	95	90	96	93		X	L. T. S. Retest of #185
2-23-66	190	93						93		X	L. T. S.
3-1-66	191	94	103	105	101	101	92	99	X		CTB
"	192	89	98	97	94	99	100	97	X		CTB
3-2-66	193	95	99	99	92	100	95	97	X		"
"	194	103	99	101	97	97	103	100	X		"
3-3-66	195	104	101	98	92	95	102	99	X		"
"	196	95	94	87	94			93		X	"
"	196A	95	96	96	91	92	100	95	X		Retest of #196 CTB
"	197										
3-4-66	198	102	99	97	92	104		98	X		CTB
"	199	97	93	96	106	103	103	98	X		"
"	200	97	97	100	97	99	97	98	X		"
"	201	95	102	100				99	X		
3-5-66	202	106	103	100	105	105	102	103	X		L. T. S.
"	203	99	94	101	98			98	X		"

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 | Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
3-7-66	204	105	104	96	102	103	95	101	X		CTB
"	205	97	99	99	99	98	95	98	X		"
"	206	99						99	X		"
3-8-66	207	98	94	101	101	100	95	98	X		"
"	208	94	97	95	100	96	92	96	X		"
"	209	98	95	95				96	X	CTB portions reworked.	
"	210	93						93	X		CTB
3-9-66	211	95	100	100	100	99	94	97	X		CTB
3-14-66	214	100	98	94				97	X		SG
3-19-66	216	98	89	91	90	93	94	93		X	SG
3-21-66	217	96	93	101	97			97	X		AS
3-22-66	218	94	95	93	94	93	91	93		X	AS
"	219	95	95	91	94	93	93	93		X	AS
"	220	96	97	97	96	97	95	96	X	AS Retest of #218	
"	221	97	95	97	95	99	96	96	X	AS Retest of #219	
"	222	96	98	98	99	97	95	97	X		AS
"	223	97	95	95	98	98	93	96	X		AS
3-23-66	224	94	98	94	96	97	96	96	X		AB
4-5-66	226	101	96	99	98	97	96	98	X		AB
4-5-66	227	97	94	96	95	95	96	96	X		AB
4-6-66	228	100	93	97	99	99	97	98	X		AB
4-20-66	229	93	95	89	90	96	93	93		X	sandy clay
4-21-66	230	94	98	91	95	91	99	95	X		rerolled silty clay
4-21-66	231	99	100	91				97	X		silty clay

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
4-21-66	232	93	98	98				96	X		silty clay
4-26-66	236	95	99	97	101	96	100	98	X		AB
"	237	100	100	97	98	97	101	99	X		AB
4-27-66	238	96	97	101	100	97	98	98	X		AB
"	239	91	97	88				90		X	silty clay
"	241	102	89	94				95		X	sandy clay
4-28-66	242	94	98	94	90	97	95	95	X		rerolled AS
"	243	100	96	101				99	X		AB
"	244	98	101	99	99	95	98	99	X		AB
4-29-66	246	98	99	90				96	X		silty clay
"	247	93	97	95	94	90	90	93		X	AS
5-2-66	248	94	91	95				93	X		AS rerolled top mtl. was loose)
5-2-66	249	96	95	93				95	X		AS
"	250	94	91	95				93		X	AS
5-3-66	251	94	99	97	97	97	93	96	X		AS
"	252	97	95	97				96	X		AS
"	253	94	94	93				94		X	AS
"	254	96	94	99	92	97	98	96	X		AS
"	255	95	93	95				95	X		AS
5-5-66	257	94	96	98	99	97	95	97	X		CTB
"	258	99	100	98				98	X		AB
5-6-66	259	96	99	94	99	100	99	99	X		CTB
"	260	101	94	100				98	X		CTB
"	261	96	95	97				96	X		AB

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 | Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
3-7-66	204	105	104	96	102	103	95	101	X		CTB
"	205	97	99	99	99	98	95	98	X		"
"	206	99						99	X		"
3-8-66	207	98	94	101	101	100	95	98	X		"
"	208	94	97	95	100	96	92	96	X		"
"	209	98	95	95				96	X		CTB portions reworked.
"	210	93						93	X		CTB
3-9-66	211	95	100	100	100	99	94	97	X		CTB
3-14-66	214	100	98	94				97	X		SG
3-19-66	216	98	89	91	90	93	94	93		X	SG
3-21-66	217	96	93	101	97			97	X		AS
3-22-66	218	94	95	93	94	93	91	93		X	AS
"	219	95	95	91	94	93	93	93		X	AS
"	220	96	97	97	96	97	95	96	X		AS Retest of #218
"	221	97	95	97	95	99	96	96	X		AS Retest of #219
"	222	96	98	98	99	97	95	97	X		AS
"	223	97	95	95	98	98	93	96	X		AS
3-23-66	224	94	98	94	96	97	96	96	X		AB
4-5-66	226	101	96	99	98	97	96	98	X		AB
4-5-66	227	97	94	96	95	95	96	96	X		AB
4-6-66	228	100	93	97	99	99	97	98	X		AB
4-20-66	229	93	95	89	90	96	93	93		X	sandy clay
4-21-66	230	94	98	91	95	91	99	95	X		rerolled silty clay
4-21-66	231	99	100	91				97	X		silty clay

TABLE VI (contd)

SUMMARY OF RELATIVE COMPACTION DATA

Road 03-Sac-5 | Cont. 03-061754

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
4-21-66	232	93	98	98				96	X		silty clay
4-26-66	236	95	99	97	101	96	100	98	X		AB
"	237	100	100	97	98	97	101	99	X		AB
4-27-66	238	96	97	101	100	97	98	98	X		AB
"	239	91	97	88				90		X	silty clay
"	241	102	89	94				95		X	sandy clay
4-28-66	242	94	98	94	90	97	95	95	X		rerolled AS
"	243	100	96	101				99	X		AB
"	244	98	101	99	99	95	98	99	X		AB
4-29-66	246	98	99	90				96	X		silty clay
"	247	93	97	95	94	90	90	93		X	AS
5-2-66	248	94	91	95				93	X		AS rerolled top mtl. was loose)
5-2-66	249	96	95	93				95	X		AS
"	250	94	91	95				93		X	AS
5-3-66	251	94	99	97	97	97	93	96	X		AS
"	252	97	95	97				96	X		AS
"	253	94	94	93				94		X	AS
"	254	96	94	99	92	97	98	96	X		AS
"	255	95	93	95				95	X		AS
5-5-66	257	94	96	98	99	97	95	97	X		CTB
"	258	99	100	98				98	X		AB
5-6-66	259	96	99	94	99	100	99	99	X		CTB
"	260	101	94	100				98	X		CTB
"	261	96	95	97				96	X		AB

TABLE VII

Percentage of Total Tests that Failed to Meet the Minimum Requirements by the 2/3 Areas Passing, Average Passing, and Both

	No. of Tests	Percentage of Total Tests
Number of test areas which failed due to the 2/3 requirement and the average was above the minimum specification.	5	10.8%
Number of test areas which failed due to minimum average RC compaction requirement and less than 1/3 failed.	1	2.2%
Number of failing test areas which do not satisfy both the 2/3 and minimum average RC compaction requirements.	40	87.0%

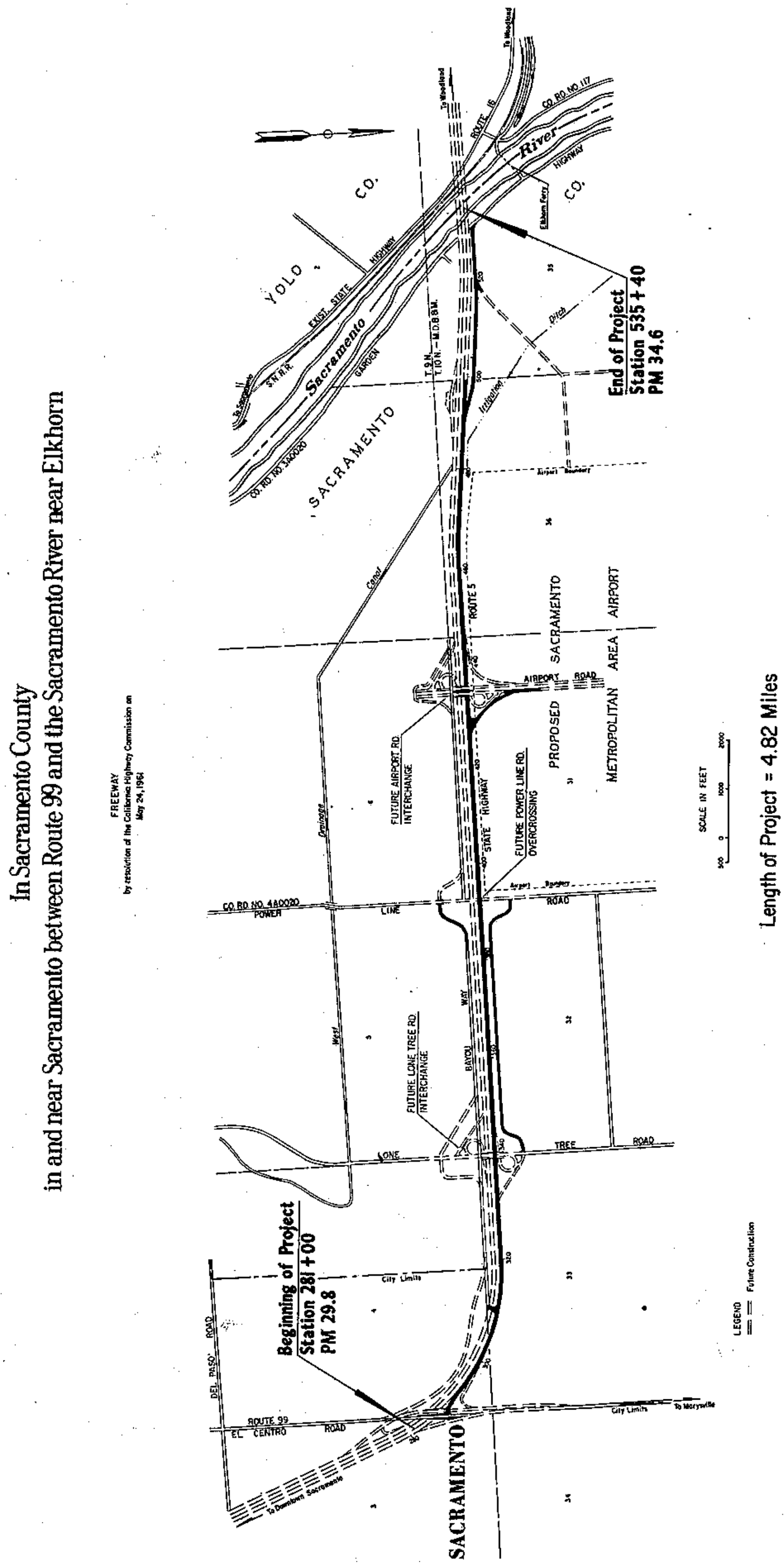
In Sacramento County
in and near Sacramento between Route 99 and the Sacramento River near Elkhorn
FREEWAY
by resolution of the California Highway Commission on May 24, 1961
End of Project
Station 535+40
PM 34.6
Beginning of Project
Station 281+00
PM 29.8
Length of Project = 4.82 Miles
SCALE IN FEET
LEGEND
Future Construction
YOLO CO.
SACRAMENTO CO.
Sacramento River
EXIST. STATE HIGHWAY
GARDEN HIGHWAY
RIVER HIGHWAY
CO. RD. NO. 117
ROUTE 16
To Woodland
Elkhorn Ferry
Ditch
Irrigation
Airport Boundary
Canal
ROUTE 5
STATE HIGHWAY
PROPOSED SACRAMENTO METROPOLITAN AREA AIRPORT
AIRPORT ROAD
FUTURE AIRPORT RD INTERCHANGE
FUTURE POWER LINE RD. OVERCROSSING
Drainage
CO. RD. NO. 4A0020
POWER LINE ROAD
West
BAYOU WAY
FUTURE LONE TREE RD INTERCHANGE
LONE TREE ROAD
City Limits
DEL PASO ROAD
ROUTE 99
EL CENTRO ROAD
To Marysville
To Downtown Sacramento
SACRAMENTO

FIGURE 1

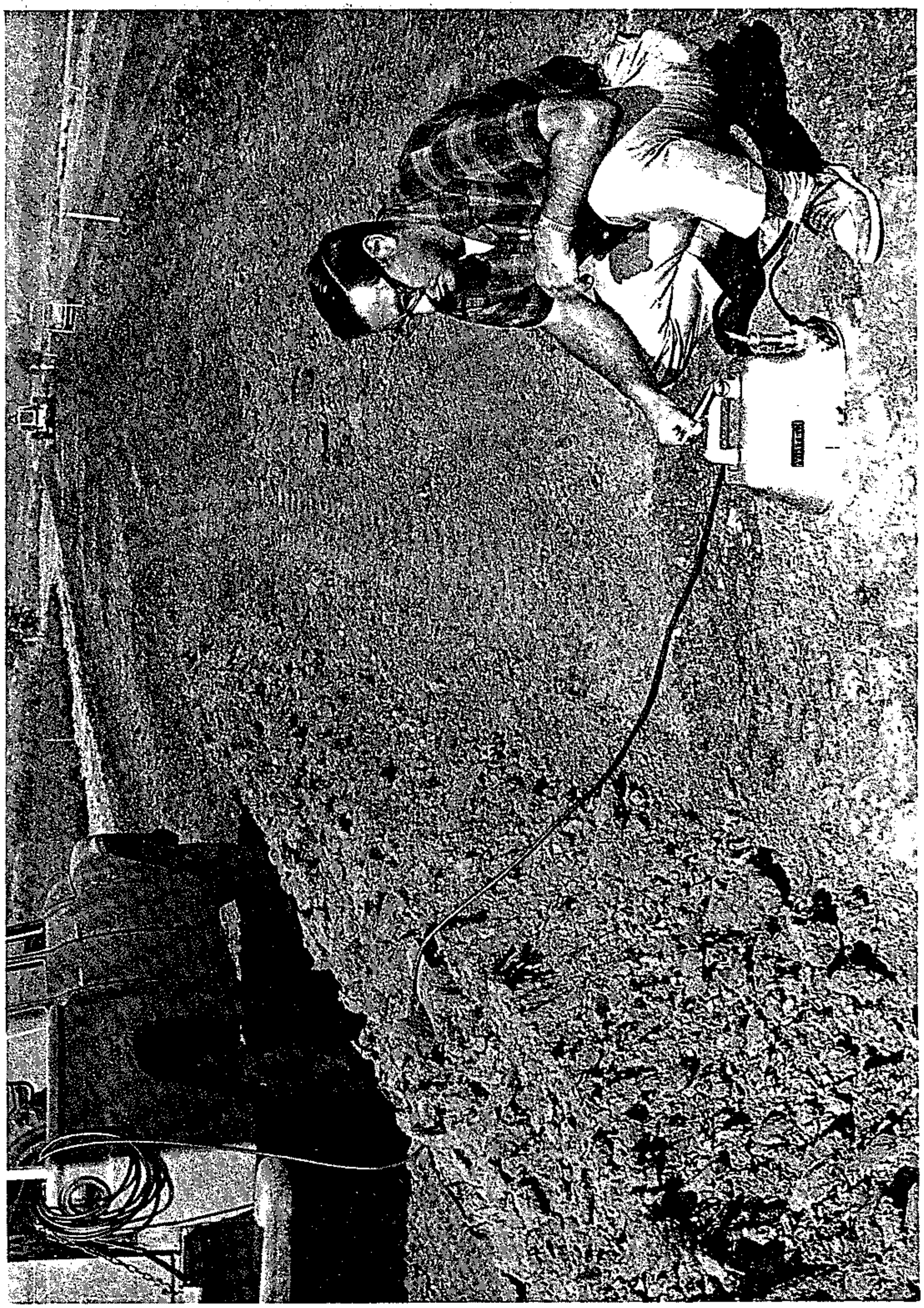

FIGURE 2

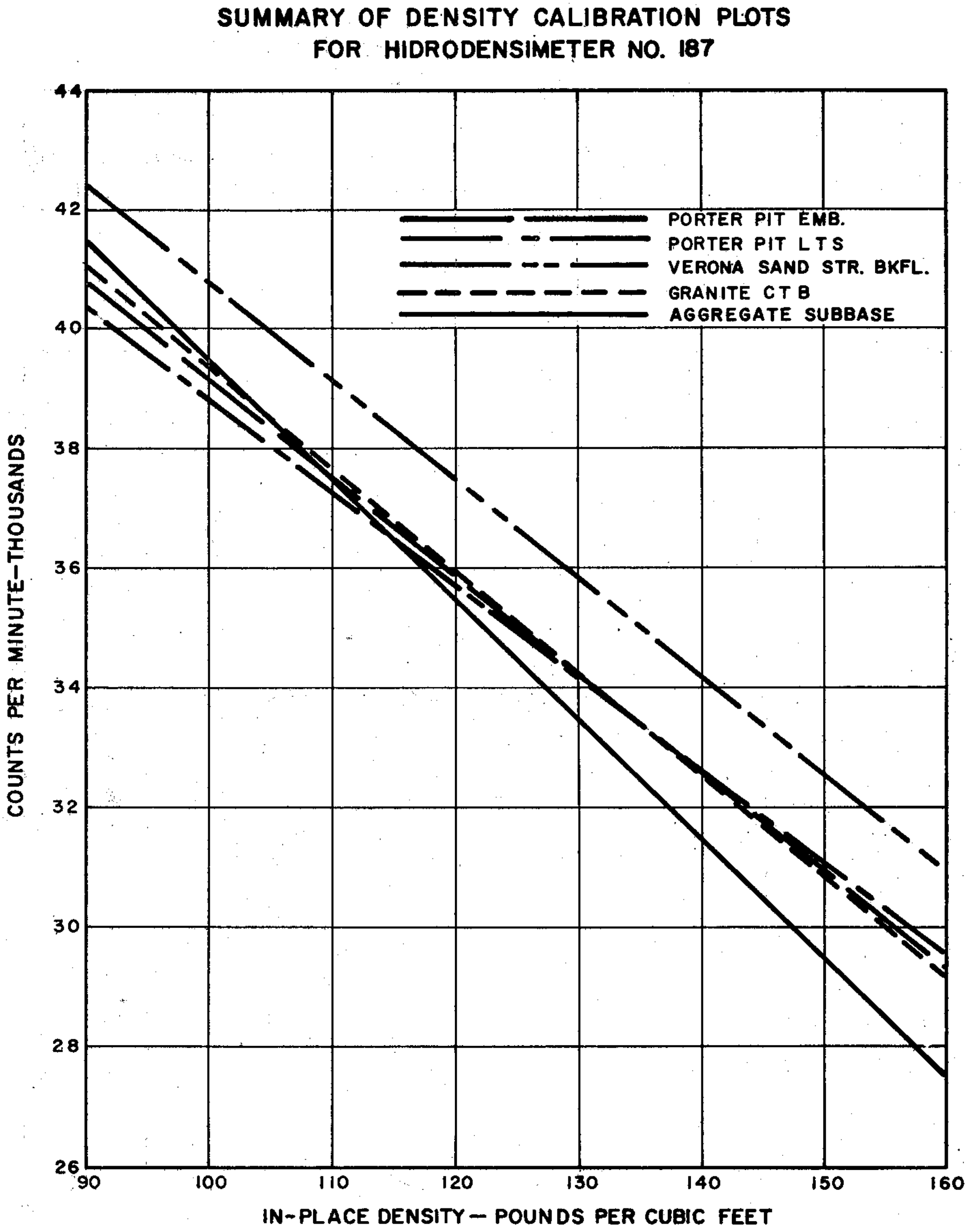
SUMMARY OF DENSITY CALIBRATION PLOTS
FOR HIDRODENSIMETER NO. 187
PORTER PIT EMB.
PORTER PIT L T S
VERONA SAND STR. BKFL.
GRANITE C T B
AGGREGATE SUBBASE
COUNTS PER MINUTE–THOUSANDS
44
42
40
38
36
34
32
30
28
26
90
100
110
120
130
140
150
160
IN-PLACE DENSITY— POUNDS PER CUBIC FEET

FIGURE 3

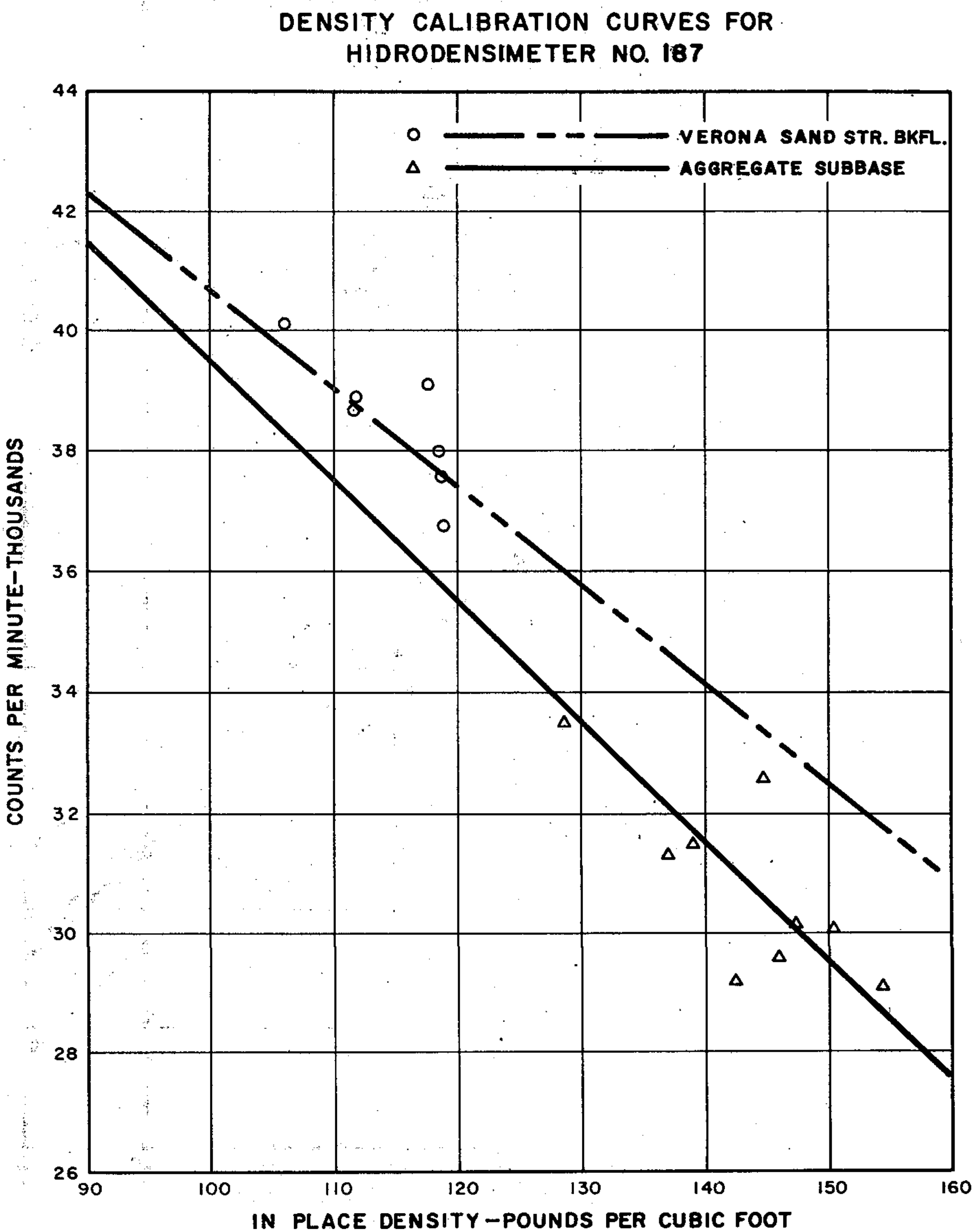
DENSITY CALIBRATION CURVES FOR
HIDRODENSIMETER NO. 187
VERONA SAND STR. BKFL.
AGGREGATE SUBBASE
COUNTS PER MINUTE–THOUSANDS
44
42
40
38
36
34
32
30
28
26
90
100
110
120
130
140
150
160
IN PLACE DENSITY–POUNDS PER CUBIC FOOT

FIGURE 4

SUMMARY OF DENSITY CALIBRATION PLOTS FOR HIDRODENSIMETER NO. 163

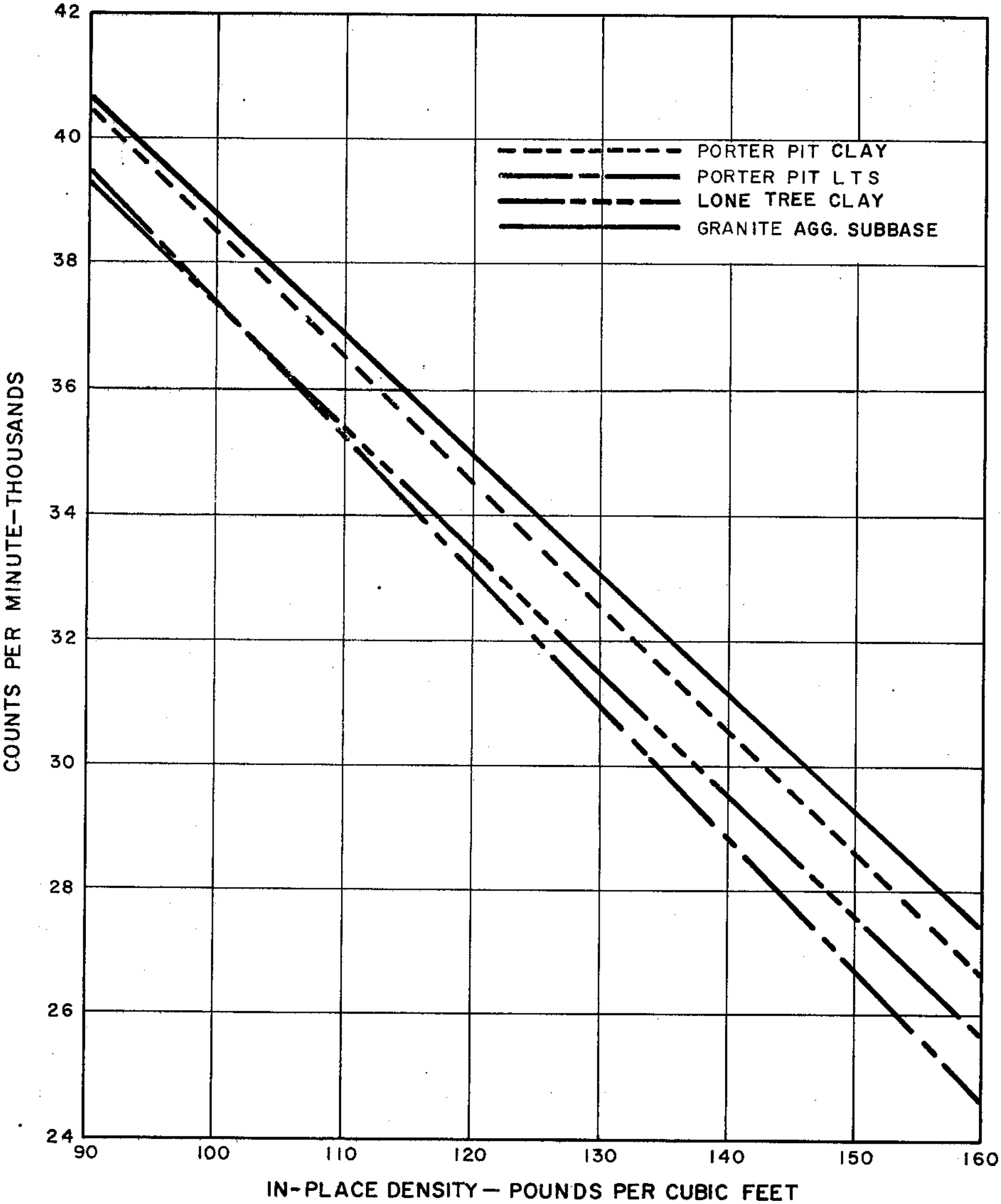

FIGURE 5

DENSITY CALIBRATION CURVES FOR
HIDRODENSIMETER NO. 163

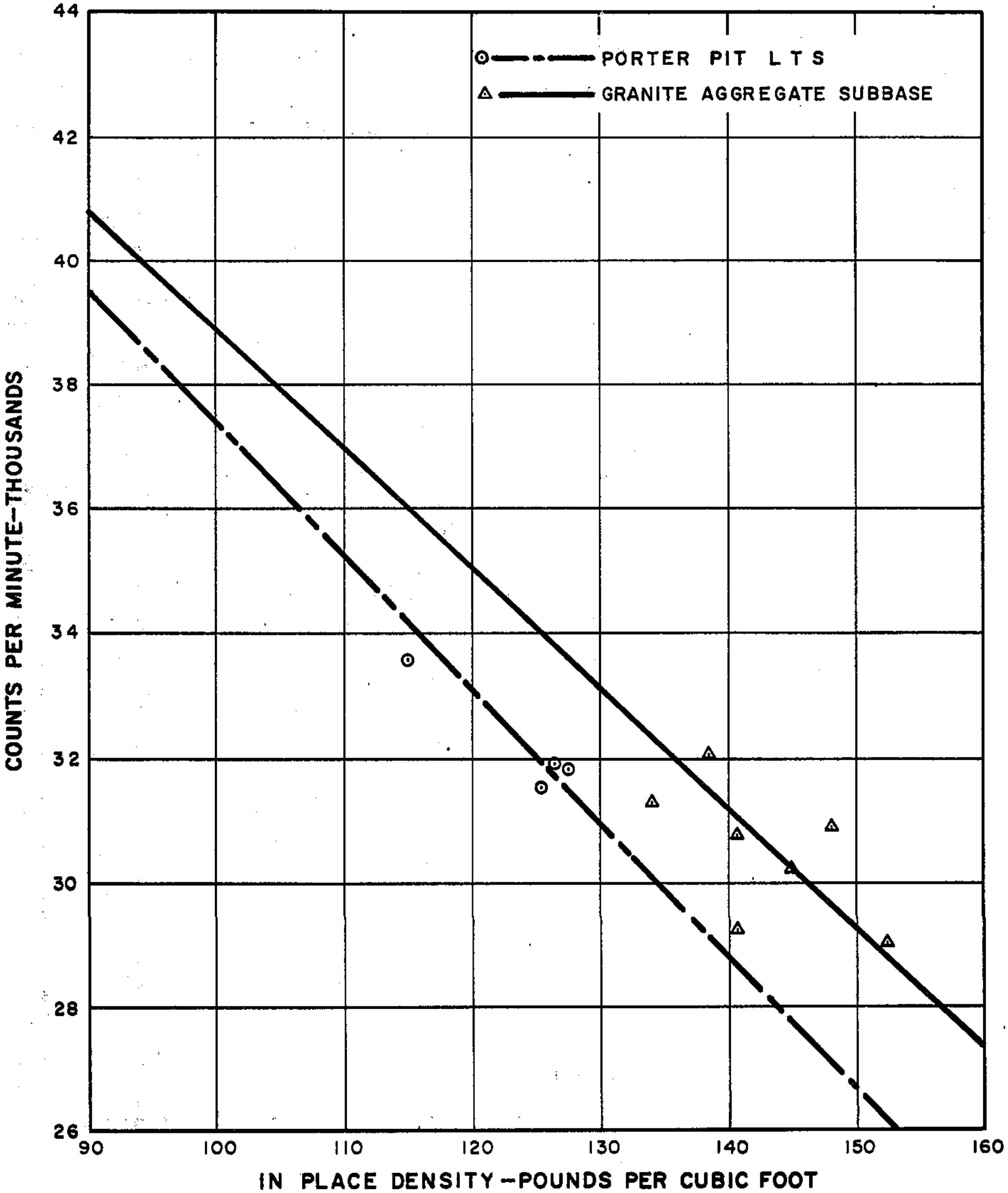

FIGURE 6

MOISTURE CALIBRATION CURVE

HDM NO. 187

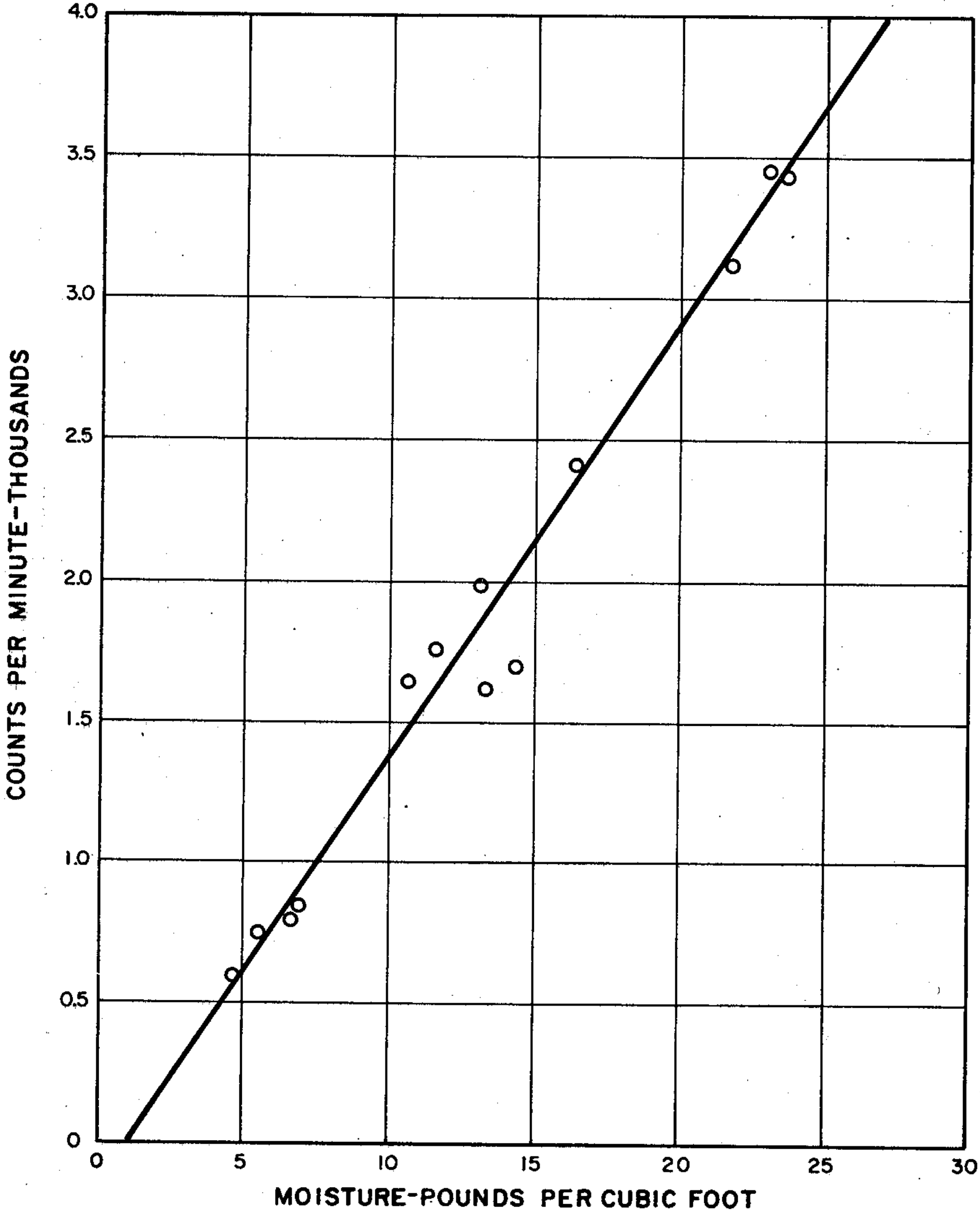

FIGURE 7

MOISTURE CALIBRATION CURVE
HDM NO. 163

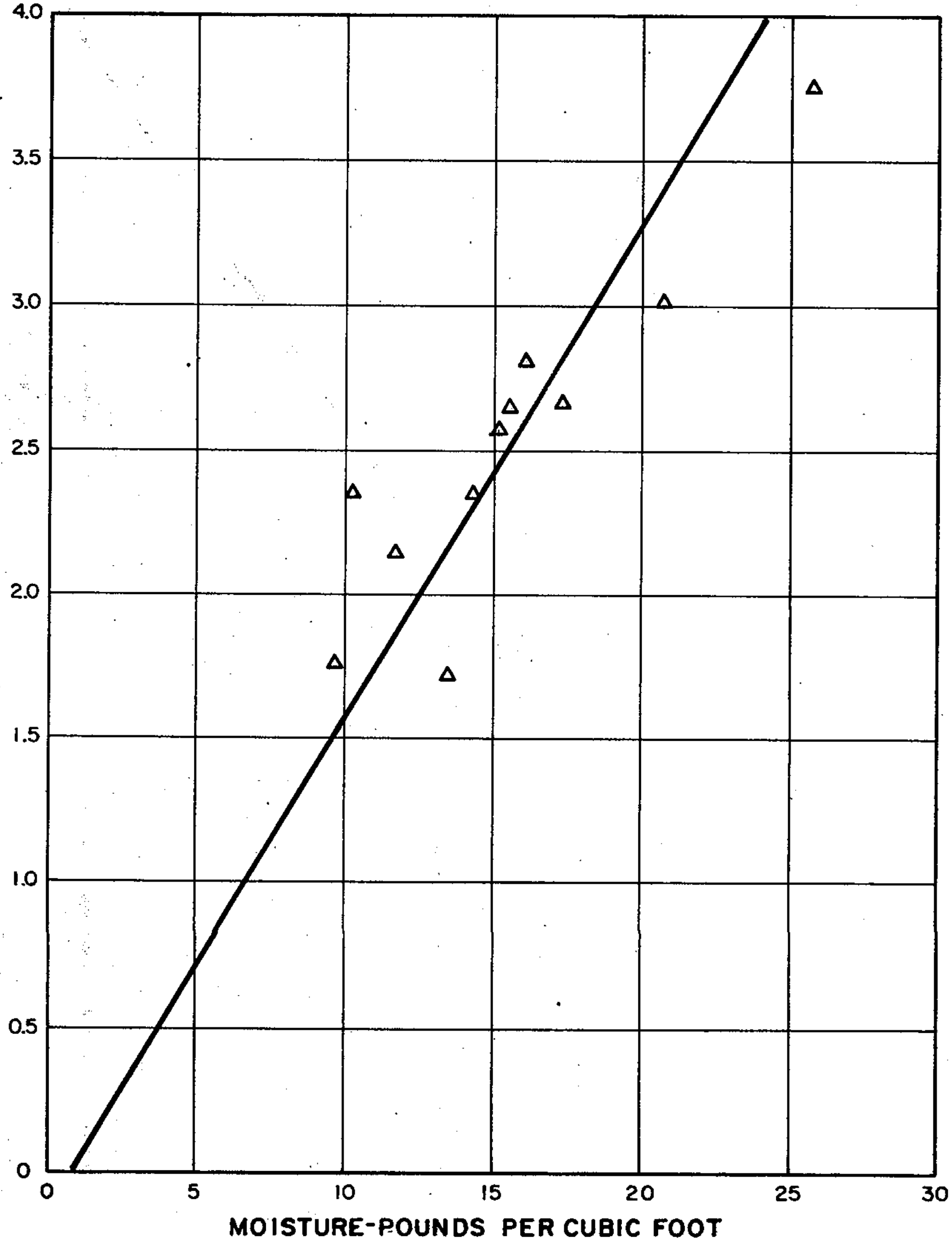

FIGURE 8

FREQUENCY DISTRIBUTION OF IMPACT COMPACTION MAXIMUM DRY DENSITIES

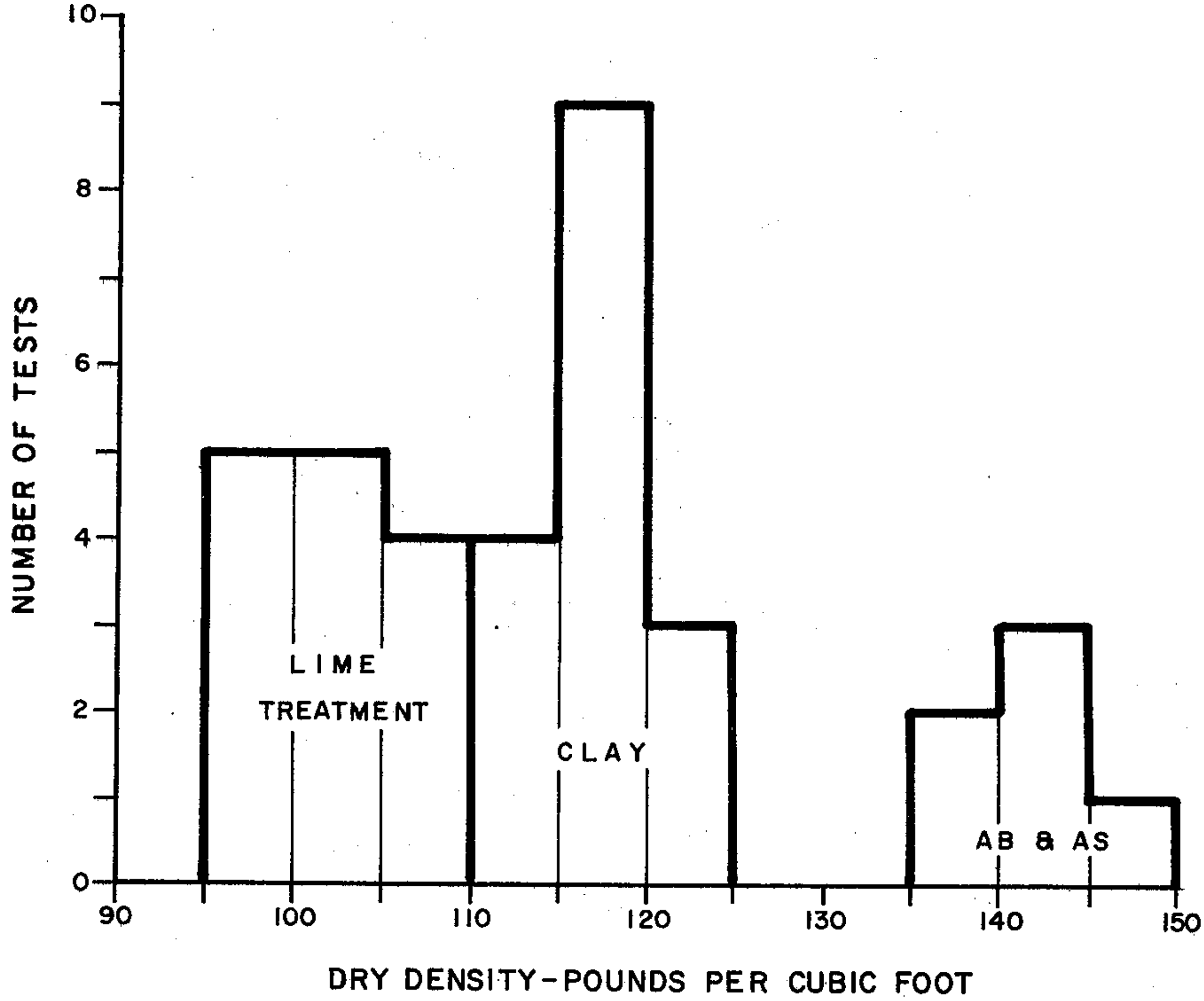

FIGURE 9

ALUMINUM MOLD AND OVERFLOW CATCHER FOR NUCLEAR GAGE CALIBRATION

SCHEMATIC DIAGRAM

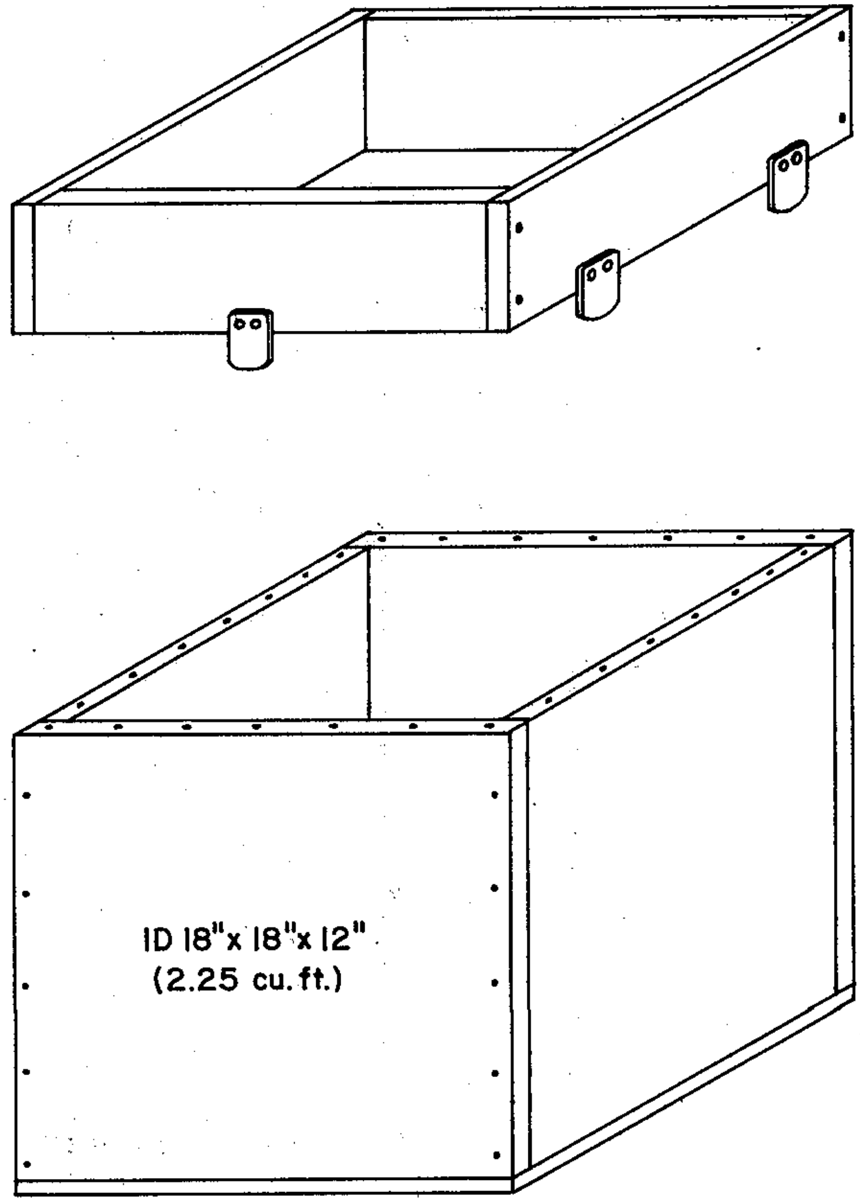

FIGURE 10

FREQUENCY DISTRIBUTION OF RELATIVE COMPACTIONS AT INDIVIDUAL TEST SITES

EMBANKMENT

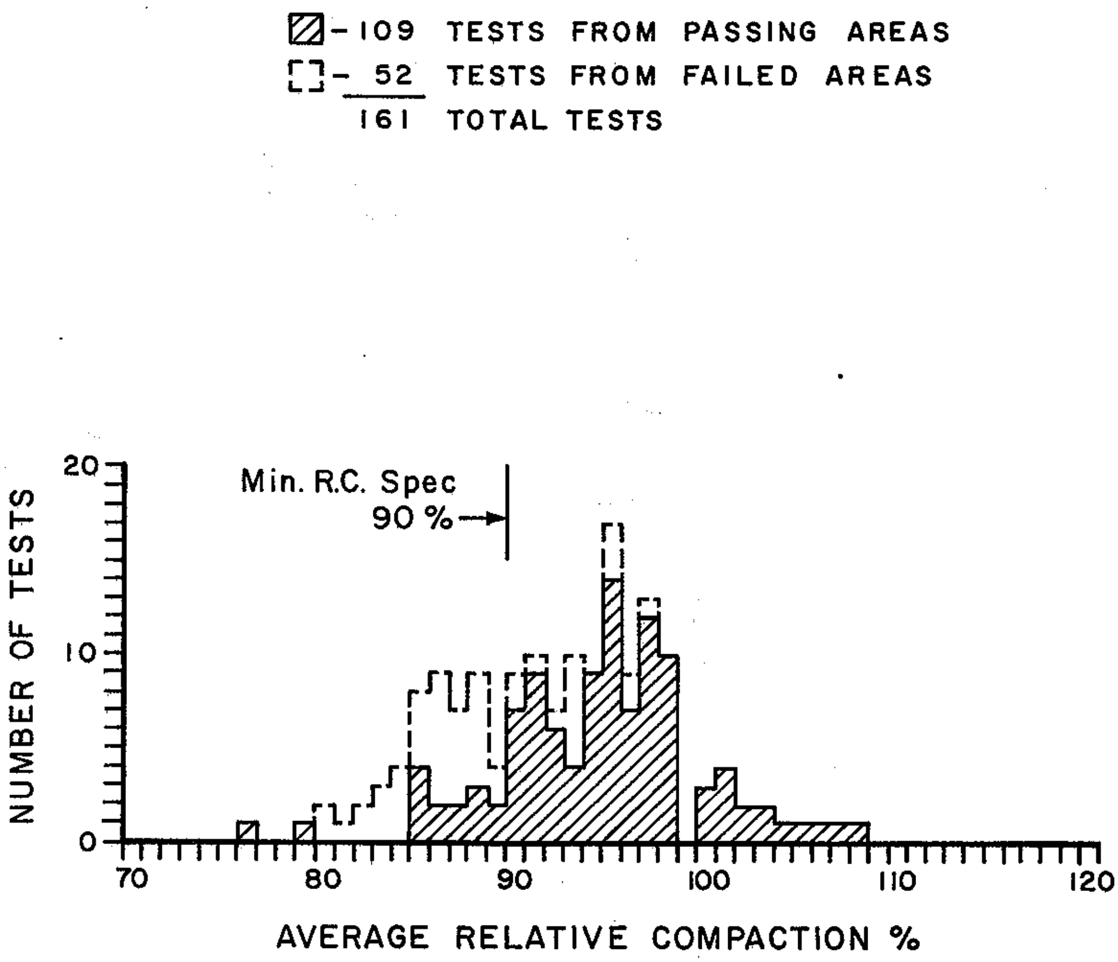

FIGURE 11

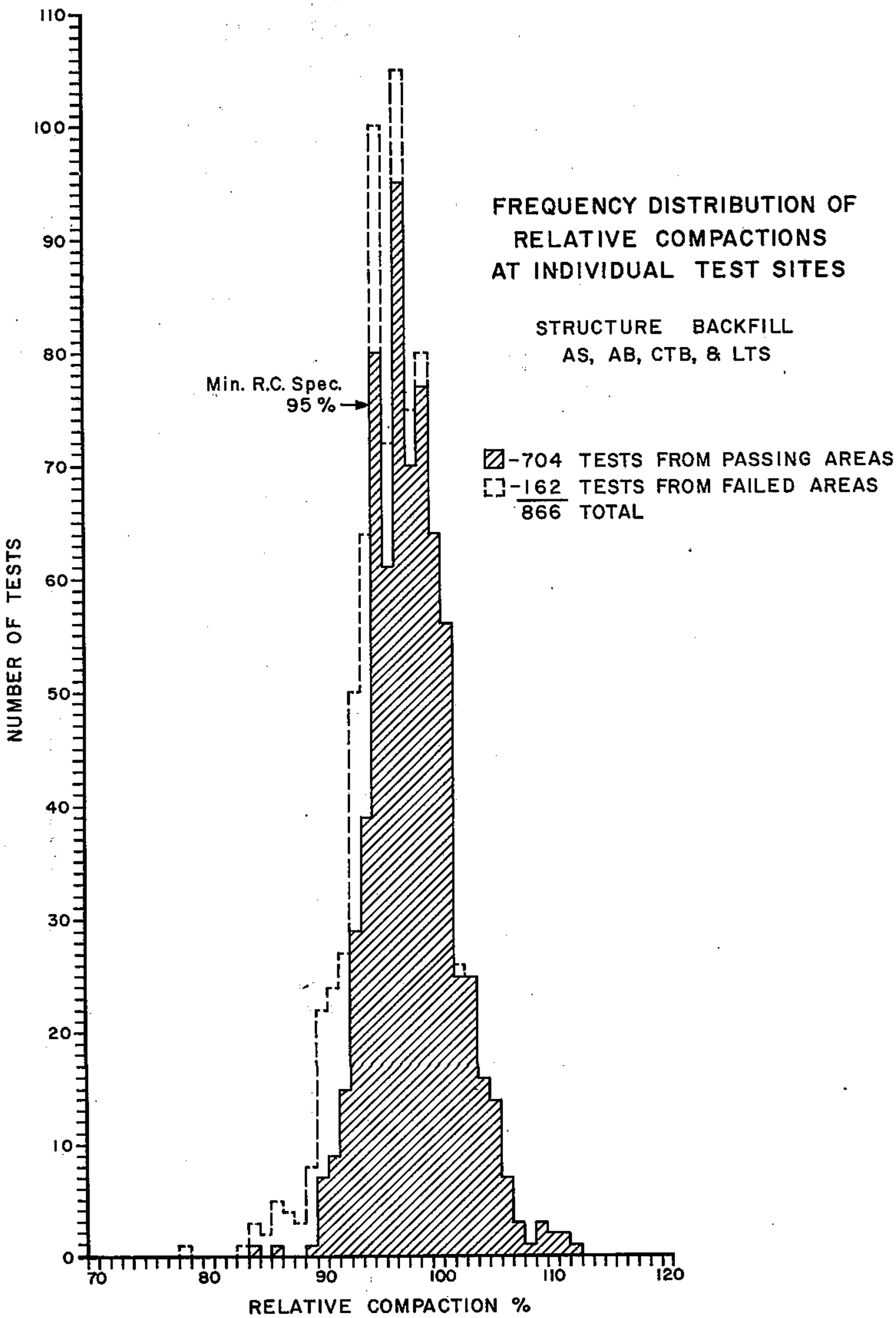
FREQUENCY DISTRIBUTION OF
RELATIVE COMPACTIONS
AT INDIVIDUAL TEST SITES
STRUCTURE BACKFILL
AS, AB, CTB, & LTS
Min. R.C. Spec.
95 %
-704 TESTS FROM PASSING AREAS
-162 TESTS FROM FAILED AREAS
866 TOTAL
NUMBER OF TESTS
RELATIVE COMPACTION %
0
10
20
30
40
50
60
70
80
90
100
110
70
80
90
100
110
120

FIGURE 12

FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR TEST SITES

EMBANKMENT

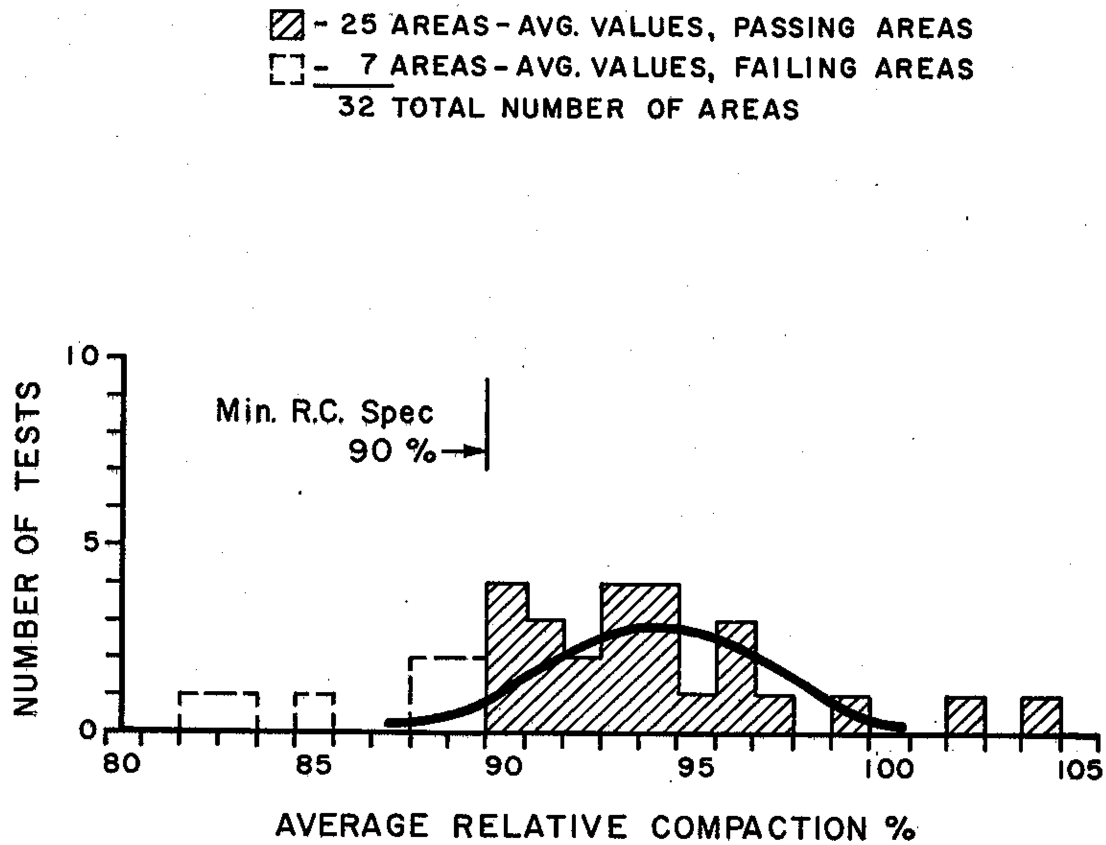

FIGURE 13

FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR TEST SITES

STRUCTURE BACKFILL
AS, AB, CTB, & LTS

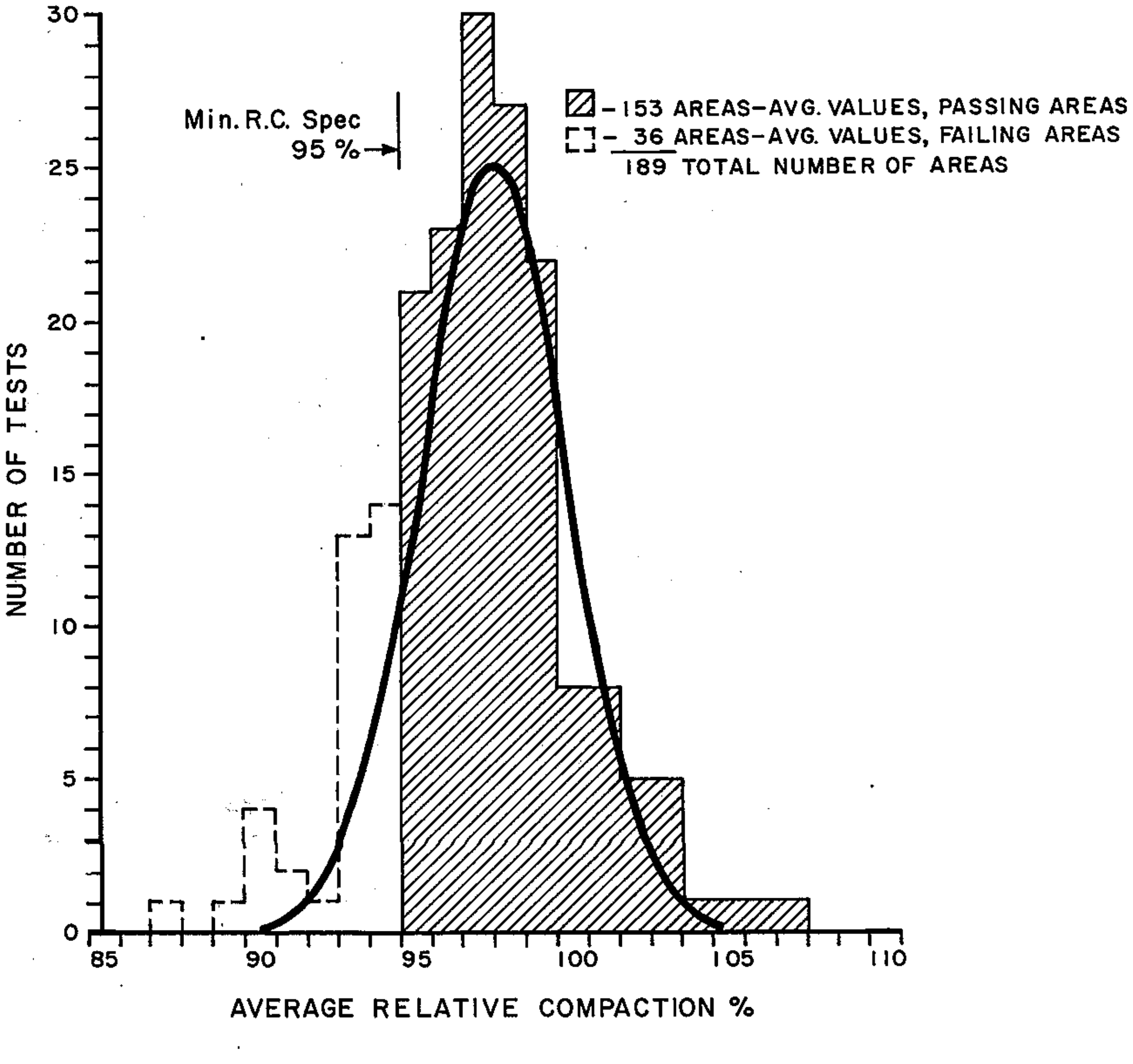

FIGURE 14

EMBANKMENT

AREAS WHICH FAILED TO MEET MINIMUM REQUIREMENTS

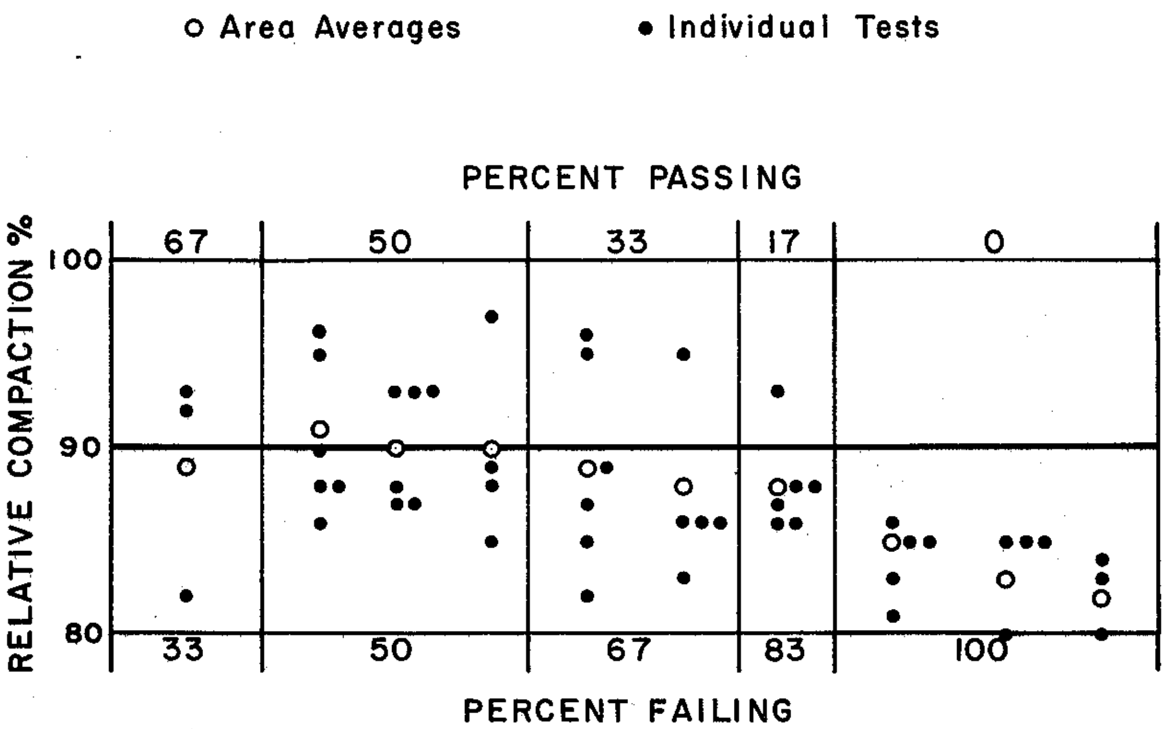

FIGURE 15

STRUCTURAL BACKFILL, AS, AB, CTB, & LTS

AREAS WHICH FAILED TO MEET 95% MINIMUM REQUIREMENT

O Area Averages ● Individual Tests

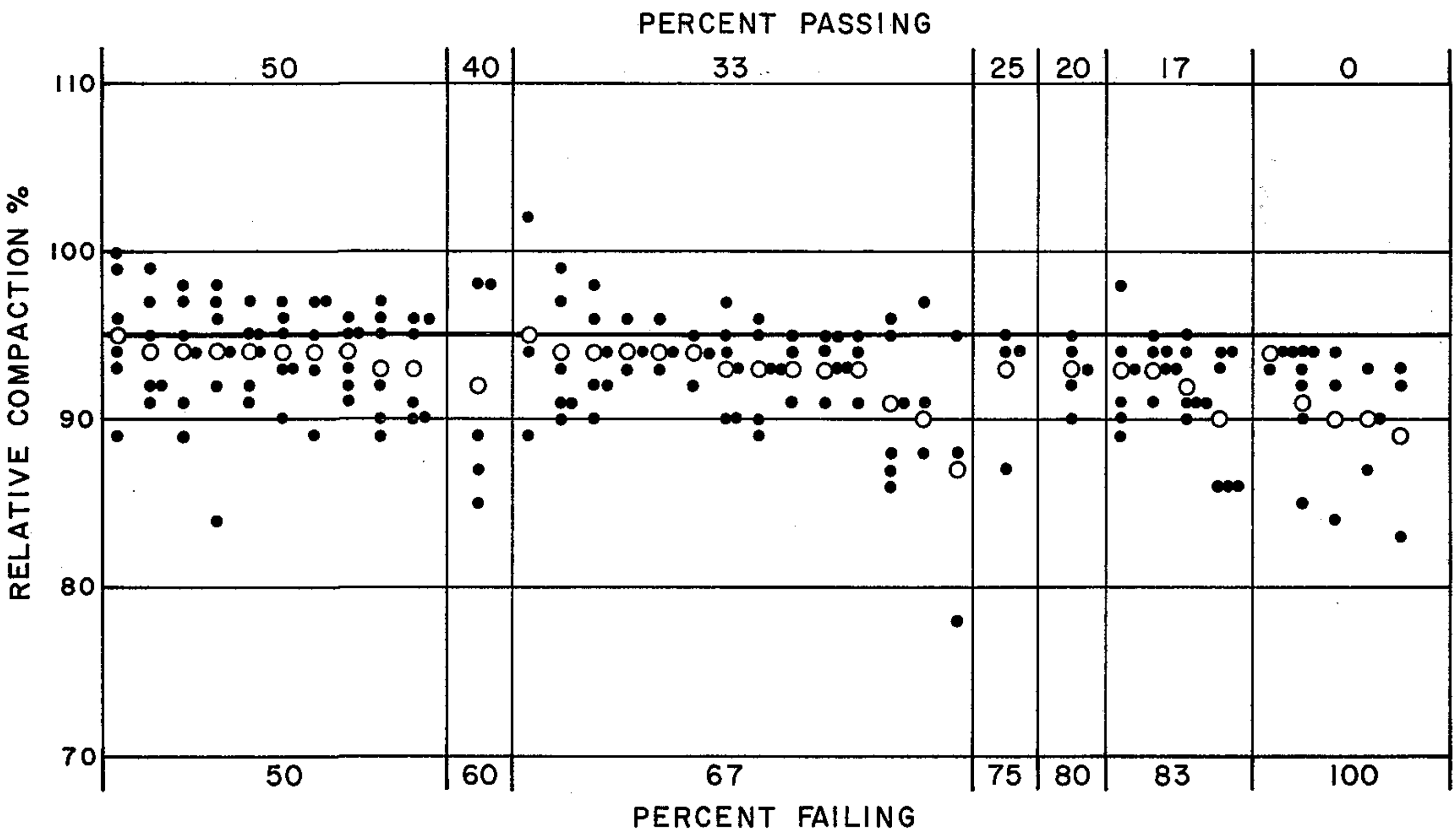

FIGURE 16

APPENDIX A

MATERIALS AND RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways

Test Method No. Calif. T-231-B
December 30, 1964
(4 pages)

METHOD OF TEST FOR RELATIVE COMPACTION OF SOILS BY NUCLEAR METHODS

SCOPE

The nuclear method of test shall be used to determine the in-place moisture and density of compacted soils and aggregates. The in-place density is the density of a soil as it exists in either the natural ground, in constructed earthwork, or after being processed and compacted. The test maximum density shall be determined as specified in Test Method No. Calif. 312 for Classes A and B Cement Treated Base and in Test Method No. Calif. 216 for untreated materials, Classes C and D Cement Treated Base and lime treated soils and aggregates.

A. APPARATUS

1. A nuclear gage for determining soil moisture and density.
2. A portable scaler to count the radiation received by the detector in the nuclear gage.
3. A standardizing device to check the operation of the gage and scaler.

B. STANDARDIZATION OF EQUIPMENT

1. At least twice a day standardize the gage to check the operation of the equipment.
2. Place the gage upon the standardizing device and take counts after the scaler has been turned on for at least fifteen minutes with the gage connected. Make five or more one-minute counts.
3. Discard any counts deviating from the average by over 200 counts and average the remaining counts. This average is to be within 250 counts of the average supplied with the equipment.

C. CALIBRATION

1. Calibration curves relating the counts obtained with the nuclear gage to the soil moisture and density will be supplied with the gage at the start of the contract.
2. Obtain comparative sand volume tests at selected intervals at the same locations as the nuclear tests. Perform the sand volume test as described in Test Method No. Calif. 216. This must be done for each general soil type encountered on the project.
3. After obtaining several comparisons the calibration relating nuclear counts to density may be modified by the method of least squares assuming a linear relationship.

D. DETERMINATION OF NUCLEAR COUNTS

1. Preparatory to making a nuclear determination, clear away all loose surface material and obtain a plane surface at least 2 feet square. In areas compacted by pneumatic-tired or smooth-wheel rollers, remove disturbed surface material to a depth of not less than 2 inches below the final surface on which the rollers have operated. Where sheepsfoot and similar type tamping rollers have been used, remove the loose surface material to a depth of not less than 2 inches below the deepest disturbance by the roller. The nuclear test may be conducted when the surface is plane to within 1/8 inch under the area covered by the gage.

2. Where a transmission type density gage is to be used, make a small hole 12 to 15 inches deep with the equipment supplied. This hole must be at 90 degrees with the plane surface. No hole is required for backscatter type gage.

3. Fill in the minor depressions, not exceeding 1/8 inch, with native fines. Place the nuclear gage on the soil surface so that all points of the bottom of the gage are in contact with the soil. Place the transmission type gage so that the rod on the gage is over the hole, and then push the rod into the hole to the desired depth.

4. Obtain a reading over a one-minute interval. Then rotate the gage 90 degrees over the same center point and obtain another one-minute reading. If these two readings do not check within 250 counts, obtain two additional readings by rotating the gage over the same center point. Average the two or more readings which are within 250 counts. This average reading constitutes one nuclear test.

E. DETERMINATION OF MOISTURE AND DENSITY OF THE SOIL

1. Using the calibration curves, convert the averaged readings to wet density and moisture content. Show the wet density in pounds of material per cubic foot and show the moisture content in pounds of water per cubic foot.

2. Determine the dry unit weight by subtracting the moisture from the wet density.

F. NUMBER AND LOCATION OF NUCLEAR TESTS

1. The nuclear test will utilize the area concept. That is, a series of tests will determine whether to accept or reject an entire area. Perform six or more nuclear tests in each area. The engineer shall determine the area based on uniformity of factors affecting nuclear testing.

2. Divide the area into two or more sections of approximately equal size. Perform two or more nuclear tests upon each section with the locations of the nuclear tests being of a random nature. (For special cases one section may be tested with three nuclear tests and considered an area). Determine the moisture and density of the soil by the nuclear tests as described in part D and E above.

F. NUMBER AND LOCATION OF NUCLEAR TESTS (Continued)

3. Average these six or more tests and perform the maximum density test on the soil obtained from the location of the nuclear test which has a value just below the average value. Determine the maximum density as specified in Test Method No. Calif. 312 for classes A and B CTB and Test Method No. Calif. 216 for all other treated and untreated soils and aggregates.

4. Care must be taken that the same soil type exists over the given area. This is so that the one maximum density test is consistent with the nuclear tests.

5. Using the maximum density test, calculate the per cent relative compaction for each nuclear test. The average of all of the nuclear determined relative compaction tests must be above the required compaction value. No more than one third of the individual tests may be below the required compaction value. If the average of all tests in one section fail to meet the required compaction value, this section may be failed even though the other sections may be passed. Thus, either sections or areas may be passed or failed.

6. When sufficient maximum density tests have been obtained, a value may be established for a soil type and only occasional check maximum densities made on that soil type.

G. DETERMINATION OF RELATIVE COMPACTION

Determine the relative compaction by either of the following:

1. Per Cent Relative Compaction

$$= \frac{\text{In-Place dry density}}{\text{Test maximum dry density}} \times 100$$

Where

In-place dry density is determined by the use of the nuclear gages as herein described.

Test maximum dry density is determined as described in Test Method No. Calif. 312 for Classes A and B CTB and Test Method No. Calif. 216 for all other treated and untreated soils and aggregates.

G. DETERMINATION OF RELATIVE COMPACTION (Continued)

2. Per Cent Relative Compaction = $\frac{L_{(nuclear)}}{g_m} \times 100$

Where

$L_{(nuclear)}$ = in-place wet density as determined by the use of the nuclear gages herein described.

g_m = maximum adjusted wet density of the compacted test specimens as described in Test Method No. Calif. 216.

REFERENCES

Test Method No. Calif. 216
Test Method No. Calif. 312

End of Text on Calif. T-231-B